TITLE OF THE INVENTION

ELECTRONIC CAMERA

BACKGROUND OF THE INVENTION

5   The present invention relates generally to an electronic camera designed to phototake a subject using a two-dimensional image pickup device, and more particularly to an electronic still camera comprising a display means for displaying an electronic image while it is phototaken or

10   after it has been phototaken.

So far, an optical finder and an electronic view finder have been known for an electronic still camera finder.

A typical optical finder is disclosed in EP0722106A2. An optical system designed to view an external image while a

15   liquid crystal display field frame is superposed on the external image is disclosed in JP-A 8-201912.

With both finders, however, it is impossible to view a phototaken electronic image through them because they are of the type that an external object is viewed through them apart

20   from the electronic image phototaken by an phototaking optical system.

Some electronic view finders comprising a liquid crystal display element of small size to be attached to a back side of a camera body are disclosed in JP-A's 8-46834 and 8-51561.

25   A loupe optical system designed to magnify and display an electronic image displayed a display element is also available.

One problem with the aforesaid electronic view finder of
the direct view type that a two-dimensional display element
is attached to the back side of the camera body is that the
two-dimensional display element used must be of small size

5 because it is impossible to increase the size of the camera
body. Another problem is that when a high-precision image is
displayed, it is difficult to take a full view of the image
with the naked eye because the display screen used is too
small. With the loupe optical system, on the other hand, it

10 is difficult to achieve a compact electronic camera because
the axial size of the loupe, that is, the size of the loupe
in the depth direction of the camera becomes large.

SUMMARY OF THE INVENTION

In view of such problems associated with the prior art,

15 an object of the present invention is to provide a compact
electronic camera designed to display an electronic image on
a two-dimensional display element while it is phototaken or
after it has been phototaken and magnify the thus displayed
image in the form of a virtual image using a compact

20 magnifying optical system comprising a curved reflecting
mirror, so that the phototaken image can be viewed with high
precision.

According to the present invention, the aforesaid object
is achieved by the provision of an electronic camera

25 comprising a phototaking optical system, a two-dimensional
image pickup element for receiving an object image formed by
said phototaking optical system, a two-dimensional display
element for displaying said object image in the form of an

image to be viewed, and a magnifying optical system for guiding said image to a viewer's eyeball, wherein said magnifying optical system includes a first reflecting surface for turning back an optical path between said two-dimensional

5   display element and said viewer's eyeball to achieve compactness, said first reflecting surface being defined by a curved surface having an action to magnify said image.

Preferably in this case, the magnifying optical system further includes a second reflecting surface located in

10 opposition to the first reflecting surface to turn back an optical path between the first and second reflecting surfaces, thereby making a distance between the two-dimensional display element and the viewer's eyeball short.

The first and second reflecting surfaces may be provided

15 by a prism member made up of a transparent medium having a refractive index (n) greater than 1.3 (n > 1.3).

In this case, the first reflecting surface may be formed on one surface of the prism member while the second reflecting surface is located at a position of the prism

20 member such that the medium is sandwiched between the first and second reflecting surfaces.

Further, the second reflecting surface may behave as a combined transmitting and reflecting surface.

It is desired that at least one of the first and second

25 reflecting surfaces be defined by a rotationally asymmetric surface having an action to make correction for aberrations produced by decentration.

Furthermore in that case, the two-dimensional image
pickup element may be located in opposition to the two-
dimensional display element.

The magnifying optical system may have two actions, one
5   to guide an image displayed on the two-dimensional display
element to the viewer's eyeball and the other to guide object
light phototaken by the phototaking optical system directly
to the viewer's eyeball.

The electronic camera of the invention may further
10 comprise between the two-dimensional image pickup element and
the two-dimensional display element a signal processing
circuit, a controller, a driver and a recording/reproducing
unit so that the object image received at the two-dimensional
image pickup element is recorded in the recording/reproducing
15 unit upon photoelectric conversion and, at the same time, is
displayed on the two-dimensional display element by the
driver via the controller during phototaking, and, upon
phototaking, a signal recorded in the recording/reproducing
unit is reproduced to display an electronic image on the two-
20 dimensional display element by the driver via the controller.

Reference is made to why the aforesaid arrangements are
adopted in the invention, and how they work. In the
invention, the magnifying optical system for projecting a
virtual image form of electronic image on a magnified scale
25 is constructed of at least one curved reflecting mirror and a
surface having a combined transmitting and reflecting action,
so that an eyepiece optical system having a large exit pupil
diameter can be achieved. This, in turn, makes it possible

to display an electronic image on the two-dimensional display element during or after phototaking so that it can be easily viewed in a virtual image form through the magnifying optical system.

5   If, in the invention, the magnifying optical system is be constructed of a prism body comprising a transparent medium having a refractive index of at least 1, the magnifying optical system can then be easily assembled because the reflecting surface can be integrated with the

10   surface having a combined transmitting and reflecting action.

If, in the invention, the curved reflecting surface of the magnifying optical system is constructed of a back-surface mirror, it is then possible to reduce the curvature of the curved reflecting mirror (or increase the radius of

15   curvature thereof), thereby reducing aberrations produced at the reflecting surface. This, in turn, makes it possible to reduce an aberration change upon movement of the viewer's eyeball and, hence, provide an easy-to-view electronic image of high precision.

20   Here let f (mm) denote the focal length of the magnifying optical system. It is then desired to satisfy

$$f < 30 \qquad \cdots \; (1)$$

In other words, the overall size of the electronic camera according to the invention can be reduced by shortening the

25   magnifying optical system. A problem with a conventional finder optical system using a transmitting lens system is that the focal length of an eyepiece optical system cannot be made short because some considerable aberrations occur due to

the fact that a main power for the optical system is obtained by a transmitting surface.

It is more preferable to satisfy

$$f < 20 \qquad \cdots \ (2)$$

This is because the optical system of smaller size can be achieved.

Here let L (mm) represent the diagonal length of the two-dimensional display element. It is then desired to satisfy

$$L < 25 \qquad \cdots \ (3)$$

In other words, the size of the electronic camera according to the invention can be reduced by reducing the magnitude of the opposite angle of the two-dimensional display element in the finder optical system. It is thus important to satisfy condition (3). If L > 25, the size of a two-dimensional display element built in an electronic camera then becomes too large to reduce the size of the electronic camera.

It is more preferable to satisfy

$$L < 18 \qquad \cdots \ (4)$$

It is most preferable to satisfy

$$L < 15 \qquad \cdots \ (5)$$

If, in the invention, the electronic view finder is used in combination with an optical finder, it is then possible to achieve an electronic camera of smaller size that is the object of the invention. In this case, it is possible to display a previously phototaken image and an object image being phototaken in a superposed fashion. It is also possible to synthesize an object image and a previously

phototaken electronic image or phototake an image through the finder while position information is displayed.

Still other objects and advantages of the invention will in part be obvious and will in part be apparent from the

5   specification.

The invention accordingly comprises the features of construction, combinations of elements, and arrangement of parts which will be exemplified in the construction hereinafter set forth, and the scope of the invention will be

10   indicated in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a conceptual diagram showing one embodiment of the electronic camera according to the invention.

Figure 2 is a sectional schematic showing one embodiment

15   of the phototaking lens system used in the electronic camera of the invention.

Figure 3 is an optical path diagram for an electronic view finder optical system according to Example 1.

Figure 4 is a block diagram of how an electronic image

20   is displayed.

Figure 5 is an optical path diagram for an electronic view finder optical system according to Example 2.

Figure 6 is an optical path diagram for an electronic view finder optical system according to Example 3.

25   Figure 7 is an optical path diagram for an electronic camera optical system according to Example 4.

Figure 8 is an optical path diagram for an electronic camera optical system according to Example 5.

Figure 9 is an optical path diagram for an electronic camera optical system using the finder optical system according to Example 5.

Figure 10 is an optical path diagram for an electronic camera optical system according to Example 6.

Figure 11 is an optical path diagram for an optical system according to Example 6 in the case where it is used in the form of a variable-magnification real image finder.

Figure 12 is an optical path diagram from an electronic camera optical system according to Example 7.

Figure 13 is an optical path diagram for an electronic camera optical system according to Example 8.

Figure 14 is a sectional schematic of an eyepiece optical system according to Example 8.

Figure 15 is an optical path diagram for an electronic camera optical system according to Example 9.

Figure 16 is a sectional schematic of an eyepiece optical system according to Example 9.

Figure 17 is an optical path diagram for an electronic camera optical system according to Example 10.

Figure 18 is a sectional schematic of an eyepiece optical system according to Example 10.

Figure 19 is a sectional schematic of an eyepiece optical system according to Example 11 during see-through.

Figure 20 is a sectional schematic of an eyepiece optical system according to Example 12.

Figure 21 is a sectional schematic of an eyepiece optical system according to Example 13.

Figure 22 is a sectional schematic of a phototaking lens according to Example 14.

Figure 23 is a perspective view of a hand-portable telephone system according to Example 15.

5   Figure 24 is a perspective view of a hand-portable telephone system according to Example 16.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Given below are examples of the electronic camera according to the invention.

10   Fig. 1 is a conceptual diagram showing an external appearance of the electronic camera according to the invention. An electronic camera shown generally by 1 comprises a phototaking lens (objective) 2. As will be described later, an image formed by the phototaking lens 2 is

15   converted to an image signal by a CCD or other two-dimensional image pickup element (not shown) located in a camera body, and then recorded in a recording/reproducing unit. When the electronic camera 1 uses an optical finder, it further includes a finder 3.

20   Fig. 2 is a sectional schematic showing one embodiment of the phototaking lens 2 of some depth, which can be used on such an electronic camera 1. In this case, this phototaking lens is designed in the form of a zoom lens. The phototaking lens system 2 comprises a first lens group L_1, a second lens

25   group L_2, a third lens group L_3 and a fourth lens group L_4. The fourth lens group L_4 comprises a transparent medium having a refractive index greater than 1, which is surrounded with a first or transmitting surface 11, a second or rotationally

asymmetric surface 12 that is decentered and has a combined transmitting and reflecting action and a third surface or rotationally asymmetric back-surface mirror 13 that is decentered and has a reflecting action, and is in such a

5   shape that light incident on the first surface 11 is reflected at the second surface 12, then reflected at the third surface 13, and finally transmits through the second surface 12. For zooming, at least two spacings of a spacing D_1 between the first lens group L_1 and the second lens group

10   L_2, a spacing D_2 between the second lens group L_2 and the third lens group L_3 and a spacing D_3 between the third lens group L_3 and the fourth lens group L_4 are made variable. Note that the rotationally asymmetric surface will be explained later.

15   Example 1

Fig. 3 is an optical path diagram for an electronic view finder optical system in the first example of such an electronic camera 1 as depicted in Fig. 1. This finder optical system comprises a two-dimensional display element 4

20   such as a liquid crystal display (LCD) and an eyepiece optical system 5. The eyepiece optical system 5 has a given finite focal length, and is made up of a transparent medium having a refractive index greater than 1, which is surrounded with a first or rotationally asymmetric surface 6 that is

25   decentered in opposition to the two-dimensional display element 4 and has a combined transmitting and reflecting action, a second surface or rotationally asymmetric back-surface mirror 7 that is decentered and has a reflecting

action and a third or transmitting surface 8. In this

optical system, display light leaving an electronic image on

the two-dimensional display element 4 is reflected at the

second surface 7 through the first surface 6, then reflected

5   at the first surface 6, and finally transmits through the

third surface 8 to arrive at a viewer's eyeball E.

It is here to be noted that the aforesaid rotationally

asymmetric surface may be formed by either a free form

surface symmetric with respect to plane, which has only one

10   plane of symmetry or an asymmetric polynomial surface (APS)

having no plane of symmetry. The latter case is

characterized in that the surface is decentered three-

dimensionally rather than in one section alone.

It is here to be noted that the free form surface

15   symmetric with respect to plane, and APS is defined by the

following polynomial:

$$
\begin{aligned}
Z = \ & C_2 \\
& + C_3 y + C_4 x \\
& + C_5 y^2 + C_6 yx + C_7 x^2 \\
& + C_8 y^3 + C_9 y^2 x + C_{10} yx^2 + C_{11} x^3 \\
& + C_{12} y^4 + C_{13} y^3 x + C_{14} y^2 x^2 + C_{15} yx^3 + C_{16} x^4 \\
& + C_{17} y^5 + C_{18} y^4 x + C_{19} y^3 x^2 + C_{20} y^2 x^3 + C_{21} yx^4 + C_{22} x5 \\
& + C_{23} y^6 + C_{24} y^5 x + C_{25} y^4 x^2 + C_{26} y^3 x^3 + C_{27} y^2 x^4 + C_{28} yx^5 + C_{29} x^6 \\
& + C_{30} y^7 + C_{31} y^6 x + C_{32} y^5 x^2 + C_{33} y^4 x^3 + C_{34} y^3 x^4 + C_{35} y^2 x^5 \\
& \qquad\qquad\qquad\qquad\qquad + C_{36} yx^6 + C_{37} x^7 \\
& \qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad \ldots\ldots \\
& \qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad \cdots \ (a)
\end{aligned}
$$

20

25

30   where C_m (m is an integer of 2 or greater) is a coefficient.

In general, the curved surface defined by polynomial (a)

has no plane of symmetry in either the X-Z plane or the Y-Z

plane (APS). If all odd terms for x are reduced to zero, however, it is then possible to obtain a free from surface having only one plane of symmetry parallel with the Y-Z plane. For instance, this may be achieved by reducing

5   coefficients for terms C_4, C_6, C_9, C_{11}, C_{13}, C_{15}, C_{18}, C_{20}, C_{22}, C_{24}, C_{26}, C_{28}, C_{31}, C_{33}, C_{35}, C_{37}, $\cdots$ in polynomial (a) to zero.

Also, if all odd terms for y are reduced to zero, it is then possible to obtain a free form surface symmetric with

10   respect to plane, which has only one plane of symmetry parallel with the X-Z plane. For instance, this may be achieved by reducing C_3, C_6, C_8, C_{10}, C_{13}, C_{15}, C_{17}, C_{19}, C_{21}, C_{24}, C_{26}, C_{28}, C_{30}, C_{32}, C_{34}, C_{36}, $\cdots$ in polynomial (a) to zero. Such plane of symmetry leads to productivity

15   improvements.

By use of either the plane of symmetry parallel with the Y-Z plane or the plane of symmetry parallel with the X-Z plane, it is possible to make effective correction for rotationally asymmetric aberrations produced due to

20   decentration.

To display an electronic image on such an electronic view finder while phototaking is conducted or after phototaking has finished, an image of a subject is photoelectrically converted by a two-dimensional image pickup

25   element 9 located at an image plane of such a phototaking lens 2 as depicted in Fig. 2, as schematically shown in Fig. 4. The resulting subject signal is recorded in a recording/reproducing unit 17 via a signal processing circuit

14 and a controller 15. During phototaking, the signal is displayed in the form of an electronic image on the two-dimensional display element 4 by a driver 16 via the controller 15. After phototaking, the signal recorded in the

5 recording/reproducing unit 17 is reproduced to display the electronic image on the two-dimensional display element 4 by the driver 16 via the controller 15.

Example 2

Fig. 5 is an optical path diagram for an electronic view

10 finder optical system according to Example 2. This optical finder system comprises a two-dimensional display element 4 and an eyepiece optical system 5. The eyepiece optical system 5 is similar to the fourth lens group L_4 shown in Fig. 2, and is made up of a transparent medium having a refractive

15 index greater than 1, which is surrounded with a first or transmitting surface 21 that is located in opposition to the two-dimensional display element 4, a second or rotationally asymmetric surface 22 that is decentered and has a combined transmitting and reflecting action, and a third surface or

20 rotationally asymmetric back-surface mirror 23 that is decentered and has a reflecting action. This eyepiece optical system has a given finite focal length. In this optical system, display light leaving an electronic image on the two-dimensional display element 4 is reflected at the

25 second surface 22 through the first surface 21, then reflected at the third surface 23, and finally transmits through the second surface 22 to arrive at a viewer's eyeball E.

Example 3

Fig. 6 is an optical path diagram for an electronic view finder optical system according to Example 3. This view finder optical system comprises a two-dimensional display

5   element 4 and an eyepiece optical system 5. The eyepiece optical system 5 has a beam splitter prism form and is made up of a transparent medium having a refractive index greater than 1, which is surrounded with a first surface 24, a second surface 25, a third surface 26 and a fourth surface 27 and

10   includes therein an obliquely extending semi-transmitting and semi-reflecting surface 28 in the form of a surface having a combined transmitting and reflecting action. For instance, the semi-transmitting and semi-reflecting surface 28 may be constructed of a surface having a reflectance of 10 to 90%

15   and a transmittance of 90 to 10%. The third surface 26 that does not oppose to the two-dimensional display element 4 is constructed of a back-surface concave mirror.

In such an arrangement, display light leaving an electronic image on the two-dimensional display element 4

20   transmits through the first surface 24 and the semi-transmitting and semi-reflecting surface 28, whereupon the light is reflected at the back-surface mirror or reflecting surface 26 and then at the semi-transmitting and semi-reflecting surface 28. Finally, the light transmits through

25   the fourth surface 27 to arrive at a viewer's eyeball E.

Thus, the eyepiece optical system 5 can be made substantially free of aberrations by constructing it of a

prism body and a surface having a major power of the back-surface mirror 26.

By applying a rotationally asymmetric surface to the entrance surface 24 of the eyepiece optical system 5 nearest to the two-dimensional display element 4, it is possible to make effective correction for image distortion. By tilting the semi-transmitting and semi-reflecting surface 28 having a combined transmitting and reflecting action with respect to the optical axis, it is also possible to prevent the two-dimensional display element 4 from projecting toward an viewer side of the electronic camera.

Example 4

Fig. 7 is an optical path diagram for an electronic cameral optical system according to Example 4. In this example, an electronic camera is designed using the finder optical system according to Example 3. A rotationally symmetric optical system is used for a phototaking lens 2. An eyepiece optical system 5 is made up of a transparent medium having a refractive index greater than 1, which is surrounded with a first surface 24, a second surface 25, a third surface 26 and a fourth surface 27, and includes therein an obliquely extending semi-transmitting and semi-reflecting surface 28 having a combined reflecting and transmitting action. The third surface 26 that does not oppose to the two-dimensional display element 4 is constructed of a back-surface concave mirror.

In this example, a see-through optical path runs through the second surface 25, semi-transmitting and semi-reflecting

surface 28 and fourth surface 27, but does not arrive at the concave mirror 26, so that an external image can be viewed apart from an image (electronic image) displayed on the two-dimensional display element 4. For phototaking, on the one

5   hand, it is thus possible to use the aforesaid see-through optical path in the eyepiece optical system 5 as an optical finder. For viewing a previously phototaken image, on the other hand, it is possible to display an electronic image recorded in the two-dimensional display element 4, so that

10   the image can be displayed on a magnified scale using the eyepiece optical system 5. This eliminates the need of constantly driving the two-dimensional display element 4, resulting in power savings and, hence, an increase in the life of the power source used.

15   Furthermore, various setting factors for an electronic camera, e.g., residual battery capacity, residual memory capacity, the possible number of phototaking, object distance information, azimuth information, and GSP position information can be displayed on the two-dimensional display

20   element 4, so that a subject can be visually identified through the see-through optical path while they are magnified by the eyepiece optical system 5.

It is noted that when it is unnecessary to view the subject through the aforesaid see-through optical path or

25   when a previously phototaken image is identified, it is possible to shield or attenuate the see-through optical path by means of a liquid crystal shutter, a mechanical shutter or

the like, so that an image through an electronic image-magnifying optical path can be better identified.

Especially when images of human figures, etc. are phototaken while they are continuously displayed on the two-
5   dimensional display element 4, it is possible to preserve an well-taken image alone or discard useless images.

In addition, if a transmitting lens system is added to the aforesaid see-through optical path, it is then possible to vary the see-through magnification (the magnification of
10   the optical finder).

Example 5

Fig. 8 is an optical path diagram for a finder optical system according to Example 5, which enables an optical finder and an electronic view finder to be changed over to
15   each other or superposed one upon another. In this finder optical system, a semi-transmitting and semi-reflecting surface having a combined reflecting and transmitting action is used for the third surface 23 of the eyepiece optical system 5 according to Example 2. A compensating optical
20   system 29 is put on a front side of the semi-transmitting and semi-reflecting surface, and a see-through optical path is provided in such a way that it overlaps an optical path for magnifying and viewing an electronic image, as in Example 4. A surface of the compensating optical system 29 to be put on
25   the third surface 23 has the same rotationally asymmetric shape as that of the third surface 23, and the opposite surface 30 thereof has the same rotationally asymmetric shape as that of the second surface 22 of the eyepiece optical

system 5. The compensating optical system 29 is made up of a
transparent material having a refractive index substantially
similar to that of the material of which the eyepiece optical
system 5 is made up.

5   Accordingly, a see-through optical path runs through the
front surface 30 of the compensating optical system 29, the
semi-transmitting and semi-reflecting surface 23 and the
second surface 22 of the eyepiece optical system 5, so that
an external image can be viewed apart from an image

10   (electronic image) displayed on the two-dimensional display
element 4.

       Fig. 9 is an optical path diagram for an electronic
camera optical system using the finder optical system
according to this example. It is here noted that an optical

15   path for a phototaking lens 2 is reverse to that for an
optical system similar to the eyepiece optical system 5
according to Example 2.

       When a subject is phototaken with such an arrangement,
an image of the subject is photoelectrically converted by a

20   two-dimensional image pickup element 9 disposed at an image
plane of the phototaking lens 2 while the aforesaid see-
through optical path is used as an optical finder, thereby
introducing it into a recording/reproducing unit 17 (Fig. 4).
When a previously phototaken image is viewed, the electronic

25   image recorded in the recording/reproducing unit 17 is
displayed on the two-dimensional display element 4, so that
the electronic image can be displayed on a magnified scale,
as explained in Example 2.

Example 6

Fig. 10 is an optical path diagram for an electronic camera optical system which also serves as a real image finder according to Example 6. In this example, the optical
5   system shown in Fig. 1 is used as a phototaking lens 2, and an eyepiece optical system 5 is made up of a transparent medium having a refractive index greater than 1 and a given finite focal length, which is surrounded with a first or rotationally asymmetric surface 31 that is decentered in
10   opposition to a two-dimensional display element 4 and has a combined transmitting and reflecting action, a second surface or rotationally asymmetric back-surface mirror 32 that is decentered and has a combined transmitting and reflecting surface, and a third or reflecting surface 33. A two-
15   dimensional image pickup element 9 and the two-dimensional display element 4 are arranged back to back. In this eyepiece optical system 5, display light leaving an electronic image on the two-dimensional display element 4 is reflected at the second surface 32 through the first surface 31, then
20   reflected at the third surface 33, then reflected at the first surface 31, and finally transmits through the second surface 32 to arrive at a viewer's eyeball E. In this electronic camera optical system, an entrance optical axis of the phototaking lens 2 is in substantial alignment with an
25   exit optical axis of the eyepiece optical system 5.

When such an arrangement is used to phototake a subject through the electronic view finder or to view a previously phototaken image, an electronic image reproduced from the

recording/reproducing unit 17 is displayed on the two-dimensional display element 4 on a magnified scale. When such an arrangement is used as a variable-magnification real image finder (telescope), the two-dimensional image pickup

5   element 9 and two-dimensional display element 4 arranged back to back are positioned off the optical path, as shown in Fig. 11, so that the original position of the two-dimensional image pickup element 9 can provide an intermediate image plane. At this plane a light beam passing through the

10 phototaking lens 2 forms an intermediate image. This intermediate image can be viewed through the eyepiece optical system 5 on a magnified scale. It is here noted that between an image pickup surface of the two-dimensional image pickup element 9 and a display surface of the two-dimensional

15 display element 4 there is a slight distance, which may be compensated for by the focusing of the phototaking lens 2.

Example 7

Fig. 12 is an optical path diagram for an electronic camera optical system which also serves as a real image

20 finder according to Example 7. In this optical system, the phototaking lens 2 of Fig. 1 is combined with the eyepiece optical system 5 of Fig. 3 (Example 1) in such a manner that an entrance optical axis of the phototaking lens 2 is in substantial alignment with an exit optical axis of the

25 eyepiece optical system 5. No further explanation of Example 7 is made because Example 7 is similar to Example 6 with the exception of the construction of the eyepiece optical system 5.

Examples 8 to 13, given below, are directed to numerical examples of the eyepiece optical system, and Example 14, given below, is directed to a numerical example of the phototaking optical system (phototaking lens). In the

5 following explanation, the eyepiece optical system will be described in the order of back ray tracing. Indeed, however, the object plane provides an image plane while the image plane provides an object plane disposed on the two-dimensional display element. The phototaking optical system

10 will be described in the order of forward ray tracing.

Prior to giving an account of each example, an explanation is made concerning the definition of coordinates for defining the position and tilt of a decentered surface forming an eyepiece optical system. Numerical data about

15 each example will be given later. It is here noted that surface Nos. are given in the order of back ray tracing for the eyepiece optical system, and in the order of forward ray tracing for the phototaking optical system.

As shown in Fig. 14, a ray passing through the center of

20 an object point and the center of a pupil to arrive at the center of an image plane is defined as an axial chief ray, an optical axis defined by a straight line segment intersecting with a stop surface in the optical system (an exit pupil surface in the case of the eyepiece optical system) is

25 defined as a Z-axis, an axis that is perpendicular with respect to the Z-axis and passes through the center of the stop surface, and lies within each decentered surface forming the optical system (that is, an axis lying within the chart

sheet of Fig. 14) is defined as a Y-axis, and an axis that is perpendicular with respect to the Z- and Y-axes is defined as an X-axis. In this connection, a direction of the axial chief ray extending from an object point to an image plane is

5   defined as a positive direction of the Z-axis, a direction toward a higher place in Fig. 14 is defined as a positive direction of the Y-axis, and a direction that is perpendicular to the chart sheet of Fig. 14 and directs from its front side to its back side is defined as a positive

10 direction of the X-axis.

In the numerical data given later, the free form surface abbreviated as FFS therein, which forms a part of the optical system of each of Examples 8, 9 and 14, is defined by the aforesaid polynomial (a), and the decentration of each

15 surface is given by the quantities of decentration of the apex position of that surface with respect to the stop surface in the optical system and the angles of tilt of the center axis of that surface (the Z-axis in polynomial (a)) with respect to the X-, Y- and Z-axes (α, β, γ). In this

20 regard, it is noted that positive values for α and β mean a counterclockwise rotation with respect to the positive direction of their respective axes and a positive value for γ means a clockwise rotation with respect to the positive direction of the Z-axis. Other factors such as the radius of

25 curvature, surface separation, refractive index and Abbe's number are also given as usual.

In Examples 10, 11, 12 and 13 basically equivalent to a coaxial optical system, too, the radius of curvature of each

surface, surface separations, the refractive index of medium
and Abbe's number are given as usual. The decentration of a
semi-transmitting and semi-reflecting surface (surface No.
3), which is inserted in each optical system and obliquely

5   with respect to an optical axis thereof and has a combined
transmitting and reflecting action, is given according to the
aforesaid definition.

In this connection, it is noted that the refractive
index given is a d-line refractive index (at a wavelength of

10   587.56 nm), and that length unit is given by mm.

Example 8

One typical external appearance of an electronic camera
according to this example is shown in Fig. 1, and an optical
path diagram therefor is given in Fig. 13. This example is

15   directed to an electronic camera using such an electronic
view finder as shown in Fig. 3. Referring to Fig. 13, such
an optical system as shown in Fig. 1 is used as a phototaking
lens 2. A finder optical system comprises a two-dimensional
display element 4 and an eyepiece optical system 5. The

20   eyepiece system 5 has a given finite focal length, and is
made up of a transparent medium having a refractive index
greater than 1, which is surrounded with a first or
rotationally asymmetric surface 6 that is decentered in
opposition to the two-dimensional display element 4 and has a

25   combined transmitting and reflecting action, a second surface
or rotationally asymmetric back-surface mirror 7 that is
decentered and has a reflecting action, and a third
transmitting or rotationally asymmetric surface 8. In this

optical system, display light leaving an electronic image on
the two-dimensional display element 4 is reflected at the
second surface 7 through the first surface 6, then reflected
at the first surface 6, and finally transmits through the

5   third surface 8 to arrive at a viewer's eyeball E with the
pupil in alignment with an exit pupil 40 surface.

Fig. 14 is a sectional schematic of the eyepiece optical
system 5 according to this example. Numerical data about
this example will be given later. The ray tracing used is a

10   back ray tracing. In this example, it is noted that the
pupil diameter is 4 mm, the angle of view is 35° in a
horizontal direction and 26.6° in a vertical direction, and
the diagonal length of the two-dimensional display element 4
is 13.94 mm. It is also noted that the focal length f_x in the

15   X-Z section is 18.929 mm and the focal length f_y in the Y-Z
section is 17.612 mm.

Example 9

An optical path diagram for an electronic camera
according to this example is shown in Fig. 15. This example

20   is directed to an electronic camera using such an electronic
view finder as shown in Fig. 5. Referring to Fig. 15, such
an optical system as shown in Fig. 1 is used as a phototaking
lens 2. A finder optical system comprises a two-dimensional
display element 4 and an eyepiece optical system 5. The

25   eyepiece system 5 has a given finite focal length, and is
made up of a transparent medium having a refractive index
greater than 1, which is surrounded with a first transmitting
or rotationally asymmetric surface 21 that is in opposition

to the two-dimensional display element 4, a second or
rotationally asymmetric surface 22 that is decentered and has
a combined transmitting and reflecting action, and a third
surface or rotationally asymmetric back-surface mirror 23

5   that is decentered and has a reflecting surface. In this
optical system, display light leaving an electronic image on
the two-dimensional display element 4 is reflected at the
second surface 22 through the first surface 21, then
reflected at the third surface 23, and finally transmits

10   through the second surface 22 to arrive at a viewer's eyeball
E with the pupil in alignment with an exit pupil 40 surface.

Fig. 16 is a sectional schematic of the eyepiece optical
system 5 according to this example. Numerical data about
this example will be given later. The ray tracing used is a

15   back ray tracing. In this example, it is noted that the
pupil diameter is 4 mm, the angle of view is 35° in a
horizontal direction and 26.6° in a vertical direction, and
the diagonal length of the two-dimensional display element 4
is 13.94 mm. It is also noted that the focal length f_x in the

20   X-Z section is 18.282 mm and the focal length f_y in the Y-Z
section is 17.973 mm.

Example 10

An optical path diagram for an electronic camera
according to this example is shown in Fig. 17. This example

25   is directed to an electronic camera using the electronic view
finder shown in Fig. 6. However, a two-dimensional display
element 4 such as an LCD is disposed over an eyepiece optical
system 5 so that ambient light, for instance, light coming

from indoor illumination equipment or the sunlight can be used as an illumination light source from above the electronic camera. Referring to Fig. 17, the optical system of Fig. 1 is used as a phototaking lens 2. The finder
5   optical system comprises the two-dimensional display element 4 and the eyepiece optical system 5. The eyepiece optical system 5 is a beam splitter prism form, and is made up of a transparent medium having a refractive index greater than 1, which is surrounded with a first surface 24, a second surface
10 25, a third surface 26 and a fourth surface 27. A semi-transmitting and semi-reflecting surface 28 having a combined reflecting and transmitting action is obliquely inserted in the prism. This semi-transmitting and semi-reflecting surface 28, for instance, is formed by a surface having a
15 reflectance of 10 to 90% and a transmittance of 90 to 10%. The third surface 26 that does not oppose to the two-dimensional display element 4 is built up of a back-surface concave mirror.

In this arrangement, display light leaving an electronic
20 image on the two-dimensional display element 4 transmits through the first spherical surface 24 and semi-transmitting and semi-reflecting surface 28, then is reflected at the spherical reflecting surface 26 of the back-surface mirror and subsequently at the semi-transmitting and semi-reflecting
25 surface 28, and finally transmits through the fourth spherical surface 27 to arrive at a viewer's eyeball E with the pupil in alignment with an exit pupil 40 surface.

Fig. 18 is a sectional schematic of the eyepiece optical system 5 according to this example. Numerical data about this example will be given later. The ray tracing used is a back ray tracing. In this example, it is noted that the

5   pupil diameter is 4 mm, the angle of view is 35° in a horizontal direction and 26.6° in a vertical direction, and the diagonal length of the two-dimensional display element 4 is 13.94 mm. It is also noted that the focal length f is 18.364 mm.

10   Example 11

A sectional schematic of an eyepiece optical system 5 according to this example upon see-through is shown in Fig. 19. This example is a numerical example of the eyepiece optical system 5 according to Example 4 upon see-through. In

15   this example, a concave lens 41 is disposed on an entrance see-through optical path side of the eyepiece optical system or beam splitter prism 5 to reduce the power of the see-through optical path to almost zero, thereby forming an afocal optical system used as a virtual image finder. When

20   an external image is viewed, extraneous light takes the see-through optical path that runs through the concave lens 41, second surface 25, semi-transmitting and semi-reflecting surface 28 and fourth surface 27, but does not arrive at a concave mirror, so that the external image can be viewed

25   apart from an image (electronic image) displayed on the two-dimensional display element 4. It is preferable to use surface reflection at the concave lens 41 on an object side, thereby constructing an Albada finder. Numerical data about

this example will be given later. The ray tracing used is a
back ray tracing. The afocal magnification is 0.8547.

Example 12

5   This example is directed to one modification of the
eyepiece optical system 5 according to Example 10, with a
section thereof shown in Fig. 20. Numerical data about this
example will be given later. The ray tracing used is a back
ray tracing. In this example, it is noted that the pupil
diameter is 4 mm, the angle of view is 30° in a horizontal
10   direction and 22.7° in a vertical direction, and the diagonal
length of the two-dimensional display element 4 is 13.94 mm.
It is also noted that the focal length f is 21.181 mm.

Example 13

        This example is directed to another modification of the
15   eyepiece optical system 5 according to Example 10, with a
section thereof shown in Fig. 21. Numerical data about this
example will be given later. The ray tracing used is a back
ray tracing. In this example, it is noted that the pupil
diameter is 4 mm, the angle of view is 35° in a horizontal
20   direction and 26.6° in a vertical direction, and the diagonal
length of the two-dimensional display element 4 is 13.94 mm.
It is also noted that the focal length f is 22.145 mm.

Example 14

        This example is directed to a phototaking lens 2 that
25   can be used with an electronic camera, with a section thereof
shown in Fig. 22. This phototaking lens 2 is a single
optical system made up of a decentered prism having the same
construction as the fourth lens group L_4 in Fig. 2. This

prism is made up of a transparent medium having a refractive index greater than 1, which is surrounded with a first transmitting or rotationally asymmetric surface 11 that is decentered at the rear of a stop 42, a second or rotationally

5 asymmetric surface 12 that is decentered and has a combined transmitting and reflecting action and a third surface or rotationally asymmetric back-surface mirror 13 that is decentered and has a reflecting action. Light from a subject, which is incident on the first surface 11 via the

10 stop 42, is reflected at the second surface 12 and then at the third surface 13, and finally trasnmits through the second surface 12 to arrive at a two-dimensional image pickup element 9 made integral with a filter and cover glass 43, where an image is formed. Preferably in view of size

15 reductions, the reflection of light at the second surface 12 is total reflection. Thus, the size reductions are ahcievable by use of the phototaking lens 2 composed of a decentered prism.

Numerical data about this example will be enumerated

20 later. The ray tracing used is a forward ray tracing. In this example, the entrance pupil diameter is 1.785 mm with the horizontal and vertical angels of view being 42.64° and 32.62°, respectively. Here assume that a Y-axis direction lies in the decentered portion of the surface and an X-axis

25 direction is defined by a direction perpendicular thereto (see Fig. 14), and let NA'yi represent an angle made in the Y-Z plane between a parallel light beam incident from an entrance side of the phototaking lens 2 and spaced 1 mm away

from an axial chief ray in the Y-direction and a light beam

leaving the phototaking lens 2, f_y denote the reciprocal of

NA'yi, that is, a Y-direction focal length, and f_x stand for

an X-direction focal length in the X-Z plane. In this

5   example, f_x is 8.292 mm and f_y is 8.076 mm.

Example 15

Fig. 23 is a perspective view of this example. This

example is directed to a system wherein each of the compact

electronic cameras described in the aforesaid examples is

10   connected or made integral with a hand-portable telephone 50,

so that a phototaken image can be sent at high speed via a

telephone circuit to a personal computer at a remote place.

If necessary information is transferred from imagewise data

stored in the personal computer to the system, it is then

15   possible to display it on a two-dimensional display element

in an electronic camera 1, so that the image can be magnified

in the form of a virtual image to display it with high-

density pixels. In Fig. 23, reference numeral 51 represents

a dial button of the hand-portable telephone 50, 52 a

20   microphone, 53 a speaker, and 54 an antenna.

Example 16

Fig. 24 is a perspective view of this example. Fig.

24(a) shows the general construction of a system, and Fig.

24(b) illustrates the construction of an electronic camera 1.

25   In this example, each of the compact electronic cameras 1

described in the aforesaid examples (e.g., the phototaking

lens 2 of Example 14 and the eyepiece optical system 5 of

Example 10) is detachably attached to a hand-portable telephone 50.

Enumerated below are numerical data about Examples 8 to 14.

Example 8

Surface No.	Radius of curvature	Surface separation	Displacement and tilt	Refractive index	Abbe's No.
Object plane	∞	-2000.0000			
1	∞(Stop)				
2	F F S [1]		(1)	1.4922	57.5
3	F F S [2]		(2)	1.4922	57.5
4	F F S [3]		(3)	1.4922	57.5
5	F F S [2]		(2)		
Image plane	∞		(4)		

F F S [1]

C_5	2.2153×10^{-2}	C_7	2.8411×10^{-2}	C_8	0
C_{10}	0	C_{12}	0	C_{14}	-3.1319×10^{-5}

F F S [2]

C_5	2.0409×10^{-3}	C_7	6.6975×10^{-3}	C_8	-1.8605×10^{-5}
C_{10}	-7.9159×10^{-5}	C_{12}	0	C_{14}	-7.5458×10^{-6}

F F S [3]

C_5	9.9446×10^{-3}	C_7	1.1558×10^{-2}	C_8	-7.0627×10^{-5}
C_{10}	-1.1373×10^{-4}	C_{12}	0	C_{14}	-4.6407×10^{-6}

Displacement and tilt

	X	Y	Z	α (°)	β (°)	γ (°)
(1)	0.000	0.000	20.124	0.00	0.00	0.00
(2)	0.000	0.000	30.714	47.72	0.00	0.00
(3)	0.000	-10.321	31.697	75.96	0.00	0.00
(4)	0.000	3.586	40.230	52.31	0.00	0.00

Example 9

Surface No.	Radius of curvature	Surface separation	Displacement and tilt	Refractive index	Abbe's No.
Object plane	∞	-2000.0000			
1	∞(Stop)				
2	F F S [1]		(1)	1.4922	57.5
3	F F S [2]		(2)	1.4922	57.5
4	F F S [1]		(1)	1.4922	57.5
5	F F S [3]		(3)		
Image plane	∞		(4)		

F F S [1]

C_5 1.8566×10^{-4} C_7 -5.9960×10^{-3} C_8 -9.3755×10^{-6}
C_{10} -1.2098×10^{-4}

F F S [2]

C_5 -7.8289×10^{-3} C_7 -1.1744×10^{-2} C_8 -1.4839×10^{-5}
C_{10} 1.2340×10^{-5}

F F S [3]

C_5 -1.9292×10^{-4} C_7 -1.8773×10^{-1} C_8 1.2657×10^{-6}
C_{10} 4.7538×10^{-4}

Displacement and tilt

	X	Y	Z	α (°)	β (°)	γ (°)
(1)	0.000	7.230	19.284	8.28	0.00	0.00
(2)	0.000	0.330	27.044	-19.41	0.00	0.00
(3)	0.000	2.351	369.458	92.61	0.00	0.00
偏心(4)	0.000	19.316	27.698	52.14	0.00	0.00

Example 1 0

Surface No.	Radius of curvature	Surface separation	Displacement and tilt	Refractive index	Abbe's No.
Object plane	∞	-1000.00			
1	∞(Stop)	20.00			
2	65.895	8.00		1.4922	57.5
3	∞	-10.00	(1)	1.4922	57.5
4	57.009	18.00		1.4922	57.5
5	187.069	4.16			
Image plane	∞				

Displacement and tilt

	X	Y	Z	α (°)	β (°)	γ (°)
(1)	0.000	0.000	0.000	45.00	0.00	0.00

Example 1 1

Surface No.	Radius of curvature	Surface separation	Displacement and tilt	Refractive index	Abbe's No.
Object plane	∞	-1000.00			
1	∞(Stop)	27.00			
2	75.396	10.00		1.4922	57.5
3	∞	10.00	(1)	1.4922	57.5
4	∞	1.00			
5	-65.000	3.00		1.4922	57.5
6	65.000	971.98			
Image	∞				

plane

Displacement and tilt

	X	Y	Z	α (°)	β (°)	γ (°)
(1)	0.000	0.000	0.000	45.00	0.00	0.00

Example 1 2

Surface No.	Radius of curvature	Surface separation	Displacement and tilt	Refractive index	Abbe's No.
Object plane	∞	-1000.00			
1	∞(Stop)	27.00			
2	75.396	10.00		1.4922	57.5
3	∞	-12.00	(1)	1.4922	57.5
4	64.455	20.00		1.4922	57.5
5	108.418	4.96			
Image plane	∞				

Displacement and tilt

	X	Y	Z	α (°)	β (°)	γ (°)
(1)	0.000	0.000	0.000	45.00	0.00	0.00

Example 1 3

Surface No.	Radius of curvature	Surface separation	Displacement and tilt	Refractive index	Abbe's No.
Object plane	∞	-1000.00			
1	∞(Stop)	27.00			
2	∞	10.00		1.4922	57.5

3	∞	-12.00	(1)	1.4922	57.5
4	52.292	20.00		1.4922	57.5
5	9.711	4.78			
Image plane	∞				

Displacement and tilt

	X	Y	Z	α (°)	β (°)	γ (°)
(1)	0.000	0.000	0.000	45.00	0.00	0.00

Example 14

Surface No.	Radius of curvature	Surface separation	Displacement and tilt	Refractive index	Abbe's No.
Object plane	∞	∞			
1	∞(Stop)				
2	F F S [1]		(1)	1.8061	50.9
3	F F S [2]		(2)	1.8061	50.9
4	F F S [3]		(3)	1.8061	50.9
5	F F S [2]		(2)		
6	∞	1.00	(4)	1.5163	64.1
7	∞	0.40		1.5163	64.1
Image plane	∞				

F F S [1]

C_5	6.9172×10^{-3}	C_7	-6.1395×10^{-2}	C_8	-8.6695×10^{-3}
C_{10}	9.3979×10^{-3}	C_{12}	-1.1168×10^{-4}	C_{14}	-6.6955×10^{-3}
C_{16}	-1.0032×10^{-3}				

F F S [2]

C_5 2.9915×10^{-2} C_7 1.8072×10^{-2} C_8 -1.4235×10^{-3}

C_{10} -1.3855×10^{-4} C_{12} 1.7627×10^{-4} C_{14} -5.1449×10^{-4}

C_{16} 2.9926×10^{-5} C_{17} -2.0752×10^{-5} C_{19} 2.2598×10^{-4}

C_{21} 2.8425×10^{-5} C_{23} -8.5787×10^{-6} C_{25} -3.9807×10^{-5}

C_{27} 4.2915×10^{-6}

FFS [3]

C_5 -5.3125×10^{-2} C_7 -4.1643×10^{-2} C_8 6.4987×10^{-4}

C_{10} 3.2017×10^{-5} C_{12} -2.1358×10^{-4} C_{14} -2.5418×10^{-4}

C_{16} -1.4899×10^{-4} C_{17} 2.0960×10^{-6} C_{19} 3.5556×10^{-5}

C_{21} 1.6431×10^{-5}

Displacement and tilt

	X	Y	Z	α (°)	β (°)	γ (°)
(1)	0.000	0.000	0.487	14.82	0.00	0.00
(2)	0.000	1.030	3.861	-43.09	0.00	0.00
(3)	0.000	3.587	4.807	100.40	0.00	0.00
(4)	0.000	-3.356	7.512	-56.54	0.00	0.00

As can be understood from the foregoing explanation, the present invention can provide a compact electronic camera which enables an electronic image to be displayed on a two-dimensional display element while it is phototaken or after it has been phototaken, so that the image can be magnified and displayed by a compact magnifying optical system constructed of a curved reflecting mirror to view a phototaken image of high precision.